

Some New Derivatives of Co(III) with Uracil, Uridine and Pyrimidine Nucleotides

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Abstract

This paper describes the synthesis of compounds of Co(III) with uracil, uridine and the nucleotides 5'UMP, 5'CMP and their characterization, carried out by elemental analysis, by studying the infrared spectra, diffuse reflectance, ¹³C NMR and conductivity measurements.

The compounds were obtained by reaction of the starting complexes *trans*-[Co(en)₂Cl₂]Cl and [Co(NH₃)₅Cl]Cl₂ with the base, nucleoside and nucleotides.

In the case of uracil (URA) and uridine (URD) compounds, indirect bonding of Co(III) to the pyrimidine ring seems to occur through the C₄=O and –NH₃(–NH₂) groups of starting complexes.

In the complexes of Co–nucleotide, bonding is inferred through the heterocyclic ring (for the Co(en)₂(5'CMP)(5'CMPH)·6H₂O complex) and through the phosphate group in the other cases.

Introduction

Within the field of interactions with nucleotides and derivatives Co(III), as well as Cr(III), has attracted special attention because its complexes, being particularly inert, are useful for determining the points where enzymes are activated or inhibited [1]. With this in mind, Cleland and Mildvan [2] have studied compounds of the CoAMP, Co(NH₃)₂ATP, Co(NH₃)₃ATP, Co(NH₃)₄ATP and similar types. Our department has also recently studied some complexes of Co(II) and Co(III) as activators of rabbit muscle glycogen phosphorylase *b* [3, 4]. Studies of such complexes are of further interest as analogies of the intermediate reaction models of the hydrolysis of ATP to ADP and inorganic phosphate catalyzed by the Co(III)–dien (diethylenetriamine) system [5].

As metal–URA(URD) coordination via N in a water medium is more difficult than for other bases (nucleosides) [6, 7], other dissolving agents such as methanol or ethyl acetate have frequently been used to promote bonding through the C₄=O group [8, 9].

In the case of 5'UMP complexes, coordination with the metal occurs mainly through the oxygens of the phosphate group [10, 11], while in 5'CMP complexes, and other purine base nucleotides, bonding generally occurs through the heterocyclic nitrogens or the phosphate group, alternatively or simultaneously [12, 18].

This paper studies derivatives of uracil, uridine, 5'UMP and 5'CMP obtained from *trans*-[Co(en)₂Cl₂]Cl and [Co(NH₃)₅Cl]Cl₂ complexes.

Experimental

The analyses of carbon, hydrogen and nitrogen were carried out in a Carlo Erba model 1106 micro-analyzer in the Institute of Bio-organic Chemistry in Barcelona and in a Perkin-Elmer 240.B in the Faculty of Chemistry, Tarragona.

The chlorine analysis was determined by the Schoniger method using a 638 Metrohm Titro Processor, by burning the sample in O₂ over sodium disulphite. Dissolution was assessed by Volhard.

Cobalt was determined by atomic absorption in a Perkin-Elmer 703 spectrophotometer. The working conditions were: λ = 240.7 nm and slit = 0.2 nm with an oxidant acetylene-air flame.

The phosphorous content was determined by using the colorimetric method of phosphomolybdo-vanadate. The measurements were carried out in a Perkin-Elmer 552 UV–Vis spectrophotometer at 390 nm and slit 2 nm.

The conductivities were measured with a Crisom 525 conductimeter. The cell constant was determined by using a water solution of KCl 10^{–2} N (*k*:1.04 cm^{–1}).

The infrared spectra were registered in solid state (KBr pellets) on a Perkin-Elmer 683 infrared spectrophotometer with an infrared data station PE 1600.

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The reflectance spectra were recorded in solid state on a Perkin-Elmer 552 UV-Vis spectrophotometer with an integrating sphere attachment.

^{13}C NMR spectra were obtained on a Varian FT-80A NMR spectrometer operating in Fourier transform mode with proton noise decoupling at frequency 20 MHz. Chemical shifts were measured relative to internal dioxane and converted to the TMS scale using $\delta^{\text{dioxane}} = 67.4$ ppm.

The complexes were prepared using uracil (Merck), uridine and nucleotides (Serva) without further purification. The starting complexes *trans*-[Co(en)₂Cl₂]Cl and [Co(NH₃)₅Cl]Cl₂ were prepared according to the usual methods described in the literature.

Synthesis of trans-[Co(en)₂Cl₂]Cl·(URA)₂, [Co(NH₃)₅Cl]Cl₂(URA), trans-[Co(en)₂Cl₂]Cl·(URD)₂, [Co(NH₃)₅Cl]Cl₂(URD)

These four complexes were obtained in an ethyl acetate medium in a way similar to that described by Goodgame *et al.* [9, 19]. 0.5 mmol of the *trans*-[Co(en)₂Cl₂]Cl (1 mmol of [Co(NH₃)₅Cl]Cl₂) and 1 mmol of uracil or uridine finely powdered were mixed and about 15 ml ethyl acetate were added. The mixture was then reflux heated by constant stirring between 9 h and 16 h depending on the case, until the reaction was complete. The product was filtered, washed with ethyl acetate (2.5 ml) and dried over P₄O₁₀.

Synthesis of Co(en)₂(5'UMP)/(5'UMPH)·10H₂O

Finely powdered dry samples (0.5 mmol of *trans*-[Co(en)₂Cl₂]Cl and 1 mmol of Na₂5'UMP) were mixed and about 15 ml ethyl acetate were added. The mixture was then reflux heated at 50 °C by constant stirring for 5 h. The green product was filtered off, washed with ethyl acetate (2.5 ml) and dried over

P₄O₁₀. Subsequently, this compound was dissolved in 20 ml of water (pH = 7.5) and the pH was lowered by means of HCl 1 N to 5.8. The solution was heated to 55 °C for 30 min in a temperature controlled bath. The complex was precipitated by addition of ethanol, then filtered, washed with ethanol and dried over P₄O₁₀.

Synthesis of Co(NH₃)₄(5'CMPH)₂Cl·2H₂O

[Co(NH₃)₅Cl]Cl₂ (1 mmol) was dissolved in the minimum quantity of distilled water and 1 mmol disodium salt of 5'CMP in 5 ml water. Both solutions were mixed and brought to pH 4.5 by means of HClO₄ 0.2 N. The resulting solution was concentrated in a rotating evaporator at 70 °C for 5 min. Heating was continued at 50 °C in a thermostatic bath for 20 h. The solution was passed through the column Sephadex G-10, and the first fraction was precipitated with ethanol. The complex was washed with ethanol and dried over P₄O₁₀.

Synthesis of Co(en)₂(5'CMP)/(5'CMPH)·6H₂O

trans-[Co(en)₂Cl₂]Cl (0.5 mmol) was dissolved in 5 ml water and 1 mmol disodium salt of 5'CMP in 5 ml water. Both solutions were mixed and heated at 50 °C in a thermostatic bath with constant stirring for about 7 h and passed through the column Sephadex G-10. The first fraction was precipitated with ethanol and dried over P₄O₁₀.

The synthesis of a 5'UMP derivative analogous to Co(NH₃)₄(5'CMPH)₂Cl·2H₂O was attempted. The isolated product was an amorphous polymeric compound not well characterized. All the attempts to obtain a well characterized derivative of 5'UMP failed.

The composition of the complexes and the analytical results appear in Table I.

TABLE I. Analytical Data and some Properties of the Compounds

Compound	Found(calculated) (%)						Colour	Melting point (°C)	Λ_{M} ($\Omega^{-1} \text{ cm}^2 \text{ mol}^{-1}$) 10 ⁻³ M at 20 °C
	C	H	N	Cl	Co	P			
<i>trans</i> -[Co(en) ₂ Cl ₂]Cl·(URA) ₂	28.31 (28.26)	4.99 (4.71)	21.92 (21.98)	21.02 (20.87)	11.21 (11.56)		green	240(d)	107
[Co(NH ₃) ₅ Cl]Cl ₂ (URA)	13.6 (13.2)	5.1 (5.2)	25.73 (27.0)	30.03 (29.37)	15.90 (16.20)		pink	245(d)	272
<i>trans</i> -[Co(en) ₂ Cl ₂]Cl·(URD) ₂	34.22 (34.11)	5.27 (5.16)	14.53 (14.47)	13.82 (13.74)	7.70 (7.60)		green	158(d)	106
[Co(NH ₃) ₅ Cl]Cl ₂ (URD)	21.81 (21.80)	5.37 (4.80)	19.04 (19.80)	21.47 (21.51)	11.59 (11.92)		pink	156(d)	257
Co(en) ₂ (5'UMP)(5'UMPH)·10H ₂ O	26.10 (26.20)	5.14 (5.80)	11.02 (11.15)		6.20 (5.86)	6.46 (6.15)	red	190(d)	99
Co(NH ₃) ₄ (5'CMPH) ₂ Cl·2H ₂ O	25.85 (25.60)	4.69 (4.90)	15.65 (16.50)	4.08 (4.20)	7.20 (6.98)	7.80 (7.30)	violet	178(d)	168
Co(en) ₂ (5'CMP)(5'CMPH)·6H ₂ O	27.84 (28.39)	6.04 (5.74)	15.59 (15.05)		7.38 (6.33)	7.09 (6.65)	violet	156(d)	55

Results and Discussion

Table II records the infrared data for the compounds obtained with uracil and uridine. The assignment has been carried out according to the literature [20–22].

The uracil compounds show splitting of the band corresponding to $\nu C_4=O$ (1671 cm^{-1}), shifting to lower frequencies, which seems to indicate charge donation by this group. Direct coordination of the base to the metal is ruled out by the presence, unmodified, of the band appearing at 293 cm^{-1} (283 cm^{-1} for the $[Co(NH_3)_5Cl]Cl_2$ complex, assigned to $\delta NMN + \delta NMCl$ [23, 24]. Some shifting also occurs on the bands corresponding to $\delta NH_2(\delta NH_3\text{asym.})$ suggesting some kind of interaction between these groups.

The uridine compounds show slight variations in the $\nu C=O$ area. Only the peak corresponding to $\nu C_4=O + \nu C=C$ (1670 s,br) shifts noticeably to lower frequencies. The ν ring ($\nu C-N$ and δNH) bands do not shift perceptibly either, although their relative intensities decrease. The bands due to the vibrations of the starting complexes stay at approximately the same frequency, with the exception of the 1598 cm^{-1} (δNH_2) and 1558 cm^{-1} ($\delta NH_3\text{asym.}$) bands, which shift noticeably and vary in intensity; this may again indicate participation of these groups in the bonding. In the lower area of the spectrum, the bands corresponding to $\nu M-N$ and $\delta NMN + \delta NMCl + \nu M-Cl$ still appear, with slight shifting probably due to overlapping with the $357, 310$ and 287 cm^{-1} bands due to ribose [19].

From all this it may be inferred that the initial complex of Co(III) does not vary its coordination

environment and there is possibly interaction by hydrogen bonding between the uracil $C_4=O$ groups and NH_3 or NH_2 of the coordinated ethylenediamine.

Table III shows the IR data for the complexes with nucleotides and their tentative assignment by comparison with the corresponding ligands. The 5'UMP compound shows variations in frequency on the bands appearing in the $\nu C=O$, ν ring and νPO_3^{-2} areas. The peak corresponding to $\nu C_2=O$ which appears around 1690 cm^{-1} [20] undergoes changes in frequency and intensity, while the $\nu C_4=O + \nu C=C + \delta NH$ peak is overlapped. The 1478 cm^{-1} band related to the pyrimidine ring ($\nu C-N$) [20] is shifted to lower frequencies and the $1284, 1267\text{ cm}^{-1}$ bands become a single peak at 1274 cm^{-1} assignable to $\nu O=C(2)_N^N$ [20]. The bands corresponding to the symmetrical and asymmetrical vibrations of the phosphate group shift noticeably. The broad band due to $\nu PO_3^{-2}\text{asym.}$ and $\nu C-O$ of the ribose ring is split and the 1114 and 1059 cm^{-1} peaks are shifted to lower frequencies, although the latter undoubtedly receives the vibrations due to $\nu C-N$ and $\nu C-C$ of the ethylenediamine group [25]. The 981 cm^{-1} band assigned to $\nu PO_3^{-2}\text{sym.}$ [26] shifts to a higher frequency and the 939 cm^{-1} band (ribose ring + ribose-phosphate stretching) [16] disappears. The metal-chloride bands in the lower area are not observed. All this seems to indicate interaction of Co(III) with the phosphate group [17, 27]. The changes observed in the peaks due to $\nu C_2=O$ and ν ring may be a consequence of bonding with the phosphate group, hydrogen bonds having probably been formed with the ethylenediamine groups thus stabilizing the structure. The second nucleotide may be expected to remain associated through stacking phenomena or

TABLE II. Infrared Data^a for the Uracil and Uridine Compounds (cm^{-1})

Tentative assignment	URA	<i>trans</i> -[Co(en) ₂ -Cl ₂]Cl·(URA) ₂	[Co(NH ₃) ₅ -Cl]Cl ₂ (URA)	URD	<i>trans</i> -[Co(en) ₂ -Cl ₂]Cl·(URD) ₂	[Co(NH ₃) ₅ -Cl]Cl ₂ (URD)
$\nu C_2=O$	1715s,br	1719s	1716s	1694s,br	1696s,sh	1696s
$\nu C_4=O + \nu C=C$	1671s,br	1670s 1647s	1669–61s,br 1645s	1681s,br 1670s,br 1615m	1681s 1665s,sh 1612m	1682s, 1675vs 1660s,sh 1610m
$\delta NH_2(\delta NH_3\text{asym})$		1595s ^b	1531sh ^c	1470s,sp	1598m ^b 1470m	1558sh ^c 1470m
ν (ring)	1452s,sp 1417s,sp 1389s,sp	1450m 1418s 1390m	1454s 1418s 1392m,sp	1421s,sp 1396s,sp	1421m 1396m	1422m 1397m
$\delta NH_2(\delta NH_3\text{sym}) + CH_2\text{ wag}$		1365w, 1316w ^b	1310s ^c		1366m, 1318m ^b	1311s ^c
$\nu M-N$		476w	490w		474w	490vw
$\delta NMN + \delta NMX + \nu M-X$		365w 293s	331w 283s		365w 292m	331w 284m

^aAbbreviations: s = strong; m = medium; b = broad; sh = shoulder; w = weak; sp = sharp; ν = stretching; δ = bending. ^bF for the *trans*-[Co(en)₂Cl₂]Cl complex bands at 1592s,sp, 1367m,sp, 1315m, 1119s,sp, 1103s,sp, 1954s,sp, 476m, 367w, 293s (cm^{-1}). ^cFor the [Co(NH₃)₅Cl]Cl₂ complex bands at 1628–1556m,br, 1310s,sp, 847s, 490w, 466vw, 329m, 283s (cm^{-1}).

TABLE III. Infrared Data for the Nucleotide Derivatives (cm⁻¹)

Tentative assignment	Na ₂ 5'UMP	Co(en) ₂ (5'UMP)- (5'UMPH)·10H ₂ O	H ₂ 5'CMP ^a	Co(NH ₃) ₄ (5'CMPH) ₂ - Cl·2H ₂ O	Na ₂ 5'CMP	Co(en) ₂ (5'CMPH)- (5'CMPH)·6H ₂ O
$\nu_{C_2=O}^b$	1704–1689br	1705s, 1696s	1723sh, 1716s, 1694s	1723s	1661s	1662s
$\nu_{C_4=O}$	1679br	1683br				
$\delta_{NH_2} + \nu_{C=N} +$ $\nu_{C=C}$			1648m 1620m,sh	1647vs,br (overlapped)	1654s 1610m	1653s 1610m
$\delta_{NH} + \nu_{C=C}$	1630w	(overlapped)				
	1478m	1468m	1542m, 1530sh	1535sh, 1530m	1531m	1526m
ν (ring)	1429m	1428m	1496w, 1451w	1493m	1499m	1493m
	1394m	1394m	1430vw, 1410w	1410w	1407w	1404w
	1349w		1374w	(overlapped)	1368vw	1377vw
	1330m		1335vw	1335w		
	1284m	1274m	1281m	1288m	1295w	1291w
	1267m		1256w	(overlapped)		
			1224m, 1165m	(overlapped)	1214w	1213w
$\nu_{PO_3}(\text{asymm.}) +$	1125s,br		1111s	1111s,br	1115s	1115s
$\nu_{CO-O}(\text{sugar})$	1092s,br	1114s	1093s	1085s,br	1083s	
	1081s,br	1059s	1070s, 1050s	1062s,br		1059s
$\nu_{PO_3}(\text{sym.})$	981s	987s	988m, 969m	990s	978s	980s
	939m		932s			

^aPrecipitated at pH = 4.5. ^bWith contribution of the δ_{NH_2} def. mode in the case of 5'CMP derivatives. s = strong; m = medium; br = broad; sh = shoulder; w = weak; ν = stretching; δ = bending.

through interaction between the bases, which might explain the variations observed in the $\nu_{C=O}$ and ν ring areas, although coordination of the two nucleotides may not be ruled out on the basis of the infrared data.

The IR spectrum of the $Co(NH_3)_4(5'CMPH)_2 \cdot Cl \cdot 2H_2O$ compound shows lesser resolution of the peaks in comparison with that of the acid form obtained at the same precipitation pH as the complex [28], as well as some shifts in frequency and changes in intensity in the ν ring and $\nu_{PO_3}^{-2}$ areas. The 1647 cm⁻¹ band corresponding to $\delta_{NH_2} + \nu_{C=N} + \nu_{C=C}$ [29] increases in intensity although its position does not vary. Other bands due to ν ring are also altered, overlapping each other, which seems to indicate that the C₂=O, NH₂ and N₃=C groups of the pyrimidine ring play some kind of part in the bonding. The PO_3^{-2} asym. area shows widespread heavy absorption with peaks registered at 1111, 1085 and 1062 cm⁻¹, and in the PO_3^{-2} sym. area a single broad band appears at 990 cm⁻¹, indicating possible metal–O(phosphate) bonding [27, 28]. In the lower area of the spectrum the band appears at 336 cm⁻¹ assignable to metal–N and the starting complex band disappears at 283 cm⁻¹ due to $\nu_{NMN} + \nu_{NMCl} + \nu_{M-Cl}$ [23], indicating freeing of the coordinated chlorine.

The $Co(en)_2(5'CMPH)(5'UMPH) \cdot 6H_2O$ complex shows variations mainly in the ν ring area. The bands corresponding to $\nu_{C_2=O}$ do not change frequency. The 1499 cm⁻¹ band assigned to $\nu_{N_3C_4}$ [20] shifts to a lower frequency and the 1368 cm⁻¹ band corre-

sponding to $\nu_{C_4}(ND_2)$ [20] shifts 9 cm⁻¹ to higher frequencies. Other pyrimidine ring bands are equally altered in the spectrum of the complex, seeming to indicate that N(3) takes part in the bonding. The bands due to the phosphate group undergo no noteworthy change. The 1083 cm⁻¹ band is not observed due to overlapping with the 1055 cm⁻¹ band of the ethylenediamine group. In any case, the ethylenediamine probably participates in hydrogen bonds, which would explain the slight shifting of the 1055 cm⁻¹ band due to $\nu_{C-C} + \nu_{C-N} + \nu_{C-H}$. In the lower area of the spectrum the 290 cm⁻¹ peak disappears, in accordance with the complete substitution of Cl.

The diffuse reflectance spectra of the compounds obtained are consistent with approximately octahedral geometries of Co(III) and the values of 10 *Dq* parameter were found using Tanabe and Sugano's Diagram [30] (Table IV). The first transition (ν_1) ${}^1T_{1g} \rightarrow {}^1A_{1g}$ appears with several associated peaks, corresponding to the transitions due to splitting of the ${}^1T_{1g}$ level through loss of symmetry. The band which appears at approximately 360 nm corresponds to the 2nd transition (ν_2) ${}^1T_{2g} \rightarrow {}^1A_{1g}$, and the 324 nm band is of the charge transfer type. The spectra for the derivatives of URA and URD show no great change with regard to the starting complexes, confirming the permanence of the initial environment of Co(III). The bands peculiar to the $\pi \rightarrow \pi^*$ transitions of the uracil ring undergo no noticeable changes, indicating weak interaction. Some apparent shifts,

TABLE IV. Diffuse Reflectance Spectra of the Complexes (bands in nm)

Compound ^a	$\pi \longrightarrow \pi^*$		$(\nu_2)^1T_{2g} \longrightarrow ^1A_{1g}$	$(\nu_1)^1T_{1g} \longrightarrow ^1A_{1g}$	$10 Dq$ (cm ⁻¹)		
URA	244s, 290sh						
<i>trans</i> -[Co(en) ₂ Cl ₂]Cl·(URA) ₂	245s, 290sh	324s	361s 430s	average 395	466s 612s	average 539	19 443
[Co(NH ₃) ₅ Cl]Cl ₂ (URA)	245s, 294s	319s	364s		465s,sh 495s,sh 558s	average 506	21 358
URD	247s, 290sh						
<i>trans</i> -[Co(en) ₂ Cl ₂]Cl·(URD) ₂	234s, 300sh	325s	361s 431s	average 396	465s,sh 612s	average 538	19 404
[Co(NH ₃) ₅ Cl]Cl ₂ (URD)	ovlp. 300sh	320s	364s		465s,sh 495s,sh 555s	average 505	21 560
Na ₂ 5'UMP	250s, 292s						
Co(en) ₂ (5'UMP)(5'UMPH)·10H ₂ O	251s, 300s		364s		496s 550s	average 523	21 090
Na ₂ 5'CMP	260s, 308s						
Co(en) ₂ (5'CMP)(5'CMPH)·6H ₂ O	272s, ovlp.	325s	363s		426s 606s	average 516	21 315
H ₂ 5'CMP	270s, 310s						
Co(NH ₃) ₄ (5'CMPH) ₂ Cl·2H ₂ O	273s, ovlp.	321s	363s		465s,sh 560s	average 512	21 351

^aFor the *trans*-[Co(en)₂Cl₂]Cl complex bands at 229s, 326s, 362s, 431s, 465s, 611s. For the [Co(NH₃)₅Cl]Cl₂ complex bands at 320s, 364s, 433s, 465s, 495s, 555s, 604s. s = strong; sh = shoulder; ovlp. = overlapped.

especially on the 247 and 290 nm bands of the URD are in fact due to overlapping with the starting complex bands. Nucleotide complexes in general show a loss in intensity and overlapping of the band appearing at around 290–300 nm as well as slight variation in the first peak. Greatest shifting occurs in the case of the Co(en)₂(5'CMP)(5'CMPH)·6H₂O complex, in accordance with bonding via N(3).

The water solubility of the complexes made calculation of the Λ_M conductivity of 10⁻³ M solutions at 20 °C possible, and the type of electrolyte for each compound could be determined [31, 32] (Table I). Values were obtained for the complexes of uracil and uridine Λ_M confirming the results of the infrared and reflectance spectra, as they indicated in all cases the presence of types of electrolytes coinciding with those of the starting complexes. This implies permanence of the initial environment of the metallic ion in the compound obtained and indirect bonding of the base or nucleoside to the metal. For the nucleotide complexes, only in the case of 5'UMP complex, the Λ_M value implies freeing of one nucleotide in water solution in its monoprotonated form.

In order to gain information about the structures of nucleotide complexes, the ¹³C NMR spectra of the ligands and complexes have been recorded in H₂O solutions with D₂O for lock and the chemical shifts are given in Table V. Dioxane was used as internal reference. The ¹³C NMR assignments were made by comparison with values in the literature [27, 33].

For the 5'UMP complex, the signals of the base carbons and ribose ring show broadening in relation to those of the free ligand, with splitting such as that of C-2, C-6 and the sugar carbons. This suggests the presence of two nucleotides interacting differently in the complex and is consistent with the presence of an associated nucleotide which is freed in solution. On the other hand, no substantial shifts are observed in the signals of ¹³C in accordance with bonding of a nucleotide to the Co(III) via O(phosphate).

For the Co(NH₃)₄(5'CMPH)₂Cl·2H₂O complex, on the contrary, the signals of the base carbons and sugar do not appear broadened or split, except for those corresponding to C-4' and C-5' which show a much lower intensity. This seems to indicate an identical and symmetrical arrangement of the nucleotides, possibly in '*trans*'. The peaks show no noteworthy shifts in comparison with the ligand spectrum, ruling out the possibility of a Co(III)–pyrimidine ring band. The slight shift of the C-2 signal may be due to participation of the C₂=O group in hydrogen bonds, thus stabilizing the structure.

In the ¹³C NMR spectrum of the Co(en)₂(5'CMP)(5'CMPH)·6H₂O complex, the signals corresponding to the C-2 and C-4 carbons are downfield shifted about two ppm. This is consistent with bonding through N(3) [34] inferred from the IR spectrum. The alterations caused by coordination via N(3) even alter the C-5 which also shifts approximately one ppm. In this case, splitting of the ribose carbons may be due to a *cis*-configuration of the two nucleotides,

TABLE V. ^{13}C NMR Spectra of Nucleotide Complexes^a

Compound	C-4	C-2	C-6	C-5	C-1'	C-4'	C-2'	C-3'	C-5'
$\text{Na}_25'\text{UMP}$	167.09	152.72	142.51	103.46	89.51	84.51 84.07	74.82	70.75	65.19 64.94
$\text{Co(en)}_2(5'\text{UMP})(5'\text{UMPH})\cdot 10\text{H}_2\text{O}$	167.00	152.50 152.40	142.85 142.49	103.33	90.47 89.53	84.42 84.02	74.79 74.38	70.67 70.52	65.06 64.83
$\text{Na}_25'\text{CMP}$	165.31	156.20	142.82	97.09	90.27	83.97 83.53	75.14	70.25	64.73 64.49
$\text{Co}(\text{NH}_3)_4(5'\text{CMPH})_2\text{Cl}\cdot 2\text{H}_2\text{O}$	165.39	156.79	143.08	97.18	90.45	84.07 83.62	75.11	70.25	64.87 64.49
$\text{Co(en)}_2(5'\text{CMP})(5'\text{CMPH})$	167.56	158.73	143.11	98.24	91.64 91.05	84.23 83.42	75.21 74.70	70.64 70.41	65.58 64.93

^aChemical shifts were measured relative to dioxane and converted to the TMS scale using $\delta_{\text{dioxane}} = 67.4$ ppm.

or a mixture of the *cis* and *trans* types [35], as the Δ_{M} value does not suggest the presence of a nucleotide not directly coordinated to the metal.

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